Dudley, Charles Benjamin
The passenger car ventilation system of the Pennsylvania Railroad Company

THE

Passenger Car Ventilation System

OF THE

PENNSYLVANIA RAILROAD COMPANY

By CHARLES B. DUDLEY, Ph. D.,
CHEMIST

Altoona, Pa.
The Pennsylvania Railroad Company
1904

THE

Passenger Car Ventilation System

OF THE

PENNSYLVANIA RAILROAD COMPANY

By CHARLES B. DUDLEY, Ph. D.,
CHEMIST

Altoona, Pa.
The Pennsylvania Railroad Company
1904

The Passenger Car Ventilation System

OF THE

Pennsylvania Railroad.

It seems not improbable that if a vote of the general traveling public could be taken on the question as to what improvement or change in passenger cars at the present time would most conduce to the comfort of passenger travel, a very large majority of the ballots would be in favor of an improvement in car ventilation. It is to be confessed, we think, that the discomfort attendant on riding a number of hours in a stuffy, over-heated passenger car, and especially the annoyance and discomfort from spending the night in an overheated, ill-ventilated sleeping car, are so great that it is not at all surprising that not only individual passengers but also the technical papers, and, indeed, the general press of the country, should from time to time break out into a tirade against the present condition of the ventilation of passenger cars. It is claimed that there are cases on record, where passenger car windows are fastened down, of passengers deliberately breaking the glass and paying for the same, in order that they might enjoy the benefits of fresh air. We think it fair to say, on the other hand, in justice to railroad officers, that the condition of affairs is not and has not been in the past entirely ignored by them. They are entirely conversant with the fact that the present passenger coach, and especially the sleeping car, is not properly ventilated, and it is not because of indifference, but because of the extreme difficulty of the problem that no more decided action has been taken in the past. If we succeed in what we have planned in this article, we think the difficulties to be overcome in the ventilation of passenger cars and the reasons for the present unsatisfactory state of affairs, will be better understood by the general public, than they are at the present time.

The question of car ventilation has been studied more or less for a number of years. Under the auspices of the Railroad Commissioners of the State of Massachusetts, some fifteen or twenty

years ago, quite a number of analyses of the air from passenger cars were made by Professor Ripley Nichols, of the Massachusetts Institute of Technology, Boston. Furthermore, not less than fifteen years ago a number of analyses of air from the cars of the Pennsylvania Railroad were made, and in 1893 or 1894 a committee of the Master Car Builders' Association made a long report on car ventilation, accompanying that report with analyses of air from sleeping cars, together with the analyses of air from other cars of passenger equipment. Still further, the records of the Patent Office show a very large number of devices which have been suggested from time to time by inventors for accomplishing this desirable end. It should not be overlooked that most passenger cars have some appliances by which fresh air is introduced, or an approximation at least toward a system of ventilation. Some of these are apparently inefficient and poor, and some are better, so that the subject has certainly not entirely escaped attention. In addition to what has preceded, it may be stated that for not less than ten years past very careful and systematic study has been put on this problem by the experts of the Pennsylvania Railroad Company.

The first step in the study of any problem is naturally to know what the present state of affairs is. This, so far as car ventilation is concerned, may be briefly stated as follows: Assuming that ventilation means change of air, and that what is desired is to get sufficient fresh air into a car and to remove the foul air, the analyses above referred to indicate that the ordinary passenger coach and sleeping car get from one-tenth to one-sixth as much air per hour through them as is required for good ventilation. There is a fairly close agreement between the analyses from all the sources mentioned above, so that we may, perhaps, be entitled to conclude that a very much larger amount of air than is at present obtained, is requisite for good ventilation in passenger cars.

Perhaps we shall best make clear what follows by asking a series of questions bearing on this subject, and answering these questions to the best of our ability. But before doing this it may not be too much to say that few problems in engineering have in our judgment, ever been undertaken which are so fraught with difficulties as the ventilation of passenger cars on railroads. A few words will make this point clear.

An ordinary passenger coach contains about 4,000 cu. ft. of space. It is proposed to take into this space sixty persons; to keep them in this space continuously without allowing them a chance to get out, for from four to six hours at a time; to keep these persons warm enough for their comfort in winter; to supply them with the proper amount of fresh air throughout the year; and at the same time to exclude from them objectionable matter, such as smoke, cinders and dust. Certainly, here are difficulties enough. The shape of the car itself, being long and narrow, the very small space compared with the large number of people, the question of keeping the people warm, and the exclusion of objectionable matter from them—each one of these items is a problem in itself, sufficiently difficult to tax the skill of the best experts, and when all are combined in one it is little wonder, apparently, that progress has been so slow.

The first question to be considered is: Is it necessary to ventilate cars both winter and summer? It would naturally be expected that the doors and windows would be sufficiently satisfactory sources of fresh air in the summer season, and that, therefore, it would only be necessary to study the subject of car ventilation for the winter. Unfortunately part of the problem, as already stated, is to exclude objectionable matter coming from without and on dusty roads, it is absolutely essential, even in warm weather, to keep the doors and windows closed on account of dust. Furthermore, smoke and cinders from the locomotive not infrequently are annoying even in the summer season, so that it seems fairly probable that a good system of ventilation should be operative both in winter and in summer, and in the studies above referred to in connection with the Pennsylvania Railroad, this phase of the case has been constantly in mind.

The next question is: Is it possible to have a ventilation system apart from the heating system? It has been urged in the technical press, and in conversation with would-be experts, that it is an easy matter to ventilate cars; simply let air in, and provide places for the foul air to get out. We are compelled to say that we think this is a very unsatisfactory view of the case. In this climate it is unendurable to let fresh air into cars in proper amount in the winter season without warming it, and, consequently, it is perfectly clear that studies on ventilation must at the same time take into account the heating system of the car. Some systems of car venti-

lation, if they may be called systems, are little more than apertures in the car, and some so-called systems simply attempt to exhaust air from the car, without providing inlets. So far as our knowledge goes, the experience with these systems is that neither of them can be used for any length of time. One can stand a little cold air for a few minutes, but, as will be seen later, when we come to consider the amount of air required, it is a little short of an absurdity to attempt to ventilate a car without at the same time warming the air.

Just at this point a very interesting question comes in, namely: Is there any means by which we may know when a car is well ventilated or not, and if so, what is this means? Upon this point it is fair to say that there does not seem to be agreement among the experts, and it is possible that as time progresses and our knowledge increases, the rule which is given below may not be adhered to, but at the present time the following is accepted as the measure of good ventilation. A space, be it a car, a room, or a theatre, or whatever may be chosen, is said to be well ventilated when a person coming into this space from the outside fresh air detects none of the odor characteristics of a badly ventilated space. Unfortunately, we have no means of measuring odors, but there is one of the accompaniments of the odor which is characteristic of badly ventilated spaces that is easily measured. Three things are continually given off from our bodies, namely, carbonic acid, water vapor and organic matter. Every time we breathe, we breathe out some carbonic acid, we breathe out some water vapor, as everyone knows who has been out on a cold morning, and we breathe out, or there is exhaled from our bodies, a certain substance which, for want of a better name, is simply called organic matter, and which is believed to be the source of the odor. Of these three substances, carbonic acid is easily measured, and it is customary to take the amount of carbonic acid in the air as the measure of good ventilation.

Many years ago, before the latest test already mentioned was introduced, it was customary to place an arbitrary limit on the amount of carbonic acid that should be allowed in the air in spaces which were said to be well ventilated. That is to say, twenty years ago, if the amount of carbonic acid in the air in any given space did not exceed 10 cu. ft. in 10,000 of the air, that space

was said to be well ventilated; but later studies have changed this view. A very large number of analyses of air have been made to find the amount of carbonic acid that is characteristic of the air when one can just begin to detect an odor. In Parkes' "Practical Hygiene," there is given a summary of a number of such analyses. The average of these analyses indicates that when two parts, or 2 cu. ft. of carbonic acid that comes from our bodies, or the bodies of animals, in 10,000 of air is found, one can just begin to detect an odor in a closed inhabited space. Therefore, two cubic feet of carbonic acid given off by human beings or animals in a closed space, in 10,000 cu. ft .of air, is taken as the test or measure of good ventilation. It should be said for information, perhaps, that the air in different parts of the world, and from many different places, has been analyzed a good many times for carbonic acid. From these it is found that there is a certain normal amount of carbonic acid in any air. The air in any room, even if the windows were wide open and the room vacant, would contain a small amount of carbonic acid. The averages of these analyses is about 4 cu. ft. in 10,000; that is, 10,000 cu. ft. of air contain normally 4 cu. ft. of carbonic acid. If we add to this the two that come from our bodies it results that a well ventilated space contains an amount of carbonic acid not exceeding 6 cu. ft. in 10,000. The various analyses referred to in the early part of this article show carbonic acid varying from about 15 to 25 parts per 10,000 in the air of cars. If we deduct the four parts which are characteristic of normal air, this leaves from 11 to 21 parts per 10,000 furnished by the passengers, and since good ventilation, as already stated, should only show an increase of carbonic acid of two parts in 10,000 over the normal, it is evident that the passenger and sleeping cars of the country are apparently getting approximately one-tenth to one-sixth the amount of air that is required for good ventilation.

The point which is being led up to, and which will be discussed in the next paragraph, is: How much air is actually required per car per hour in order to give satisfactory ventilation? Before taking up this question, however, there is another question that must be considered, and that is: How much carbonic acid do human beings give off per person per hour? A good many experiments have been made on this point by different investigators. It is found,

if we are right, that men give off more than women, and children less than either, and that a man at vigorous work gives off more than a man in idleness. The studies show, so it is stated, at least in Parkes' "Practical Hygiene," that the average of a mixed community, men, women and children, as they occur, give off 6-10 of a cubic foot of carbonic acid per person per hour, part of this coming from the lungs and part from the skin. Since the people traveling on cars may be fairly regarded as representing a mixed community, that is to say, men, women and children, it will, perhaps, be safe for us in our calculations to use this figure, 6-10 of a cubic foot of carbonic acid per person per hour.

This brings us to the discussion of the question just previously stated, namely: How much air per car per hour is needed to properly ventilate a car? It is apparent that if each person gives off 6-10 of a cubic foot of carbonic acid per hour, and there are 60 people in the car, there would be generated or given off in the car per hour, 36 cu. ft. of carbonic acid. The problem then becomes: How much air is it essential to mix with these 36 ft. of carbonic acid in order that the resulting mixture shall contain 2 cu. ft. of carbonic acid in 10,000 of the mixture in addition to the 4 cu. ft. which are characteristic of the normal air? This is a very simple proportion, namely, if 10,000 cu. ft. contain 2, how many thousand cubic feet will be required to contain 36 cu. ft. on the same ratio? Making the calculation and we reach the astounding figure that in order to have a passenger car well ventilated, in accordance with the tests and data that have already been given, it actually requires that 180,000 cu. ft. of fresh air per hour should be taken through the car. We fancy most railroad operating officials, as well as the general public, who have not given the subject careful consideration, will be astonished at this figure. It actually means that the air in a car must be changed about 45 times an hour or once in about 80 seconds.

It is fair to say that in the best information which we can get hold of on ventilation, this is the figure adopted, namely, 3,000 cu. ft. of fresh air per person per hour are requisite for good ventilation of closed spaces. In other words, the best authorities that we can consult on the subject lead up to this figure. Two points, however, may be mentioned as possibly modifying these requirements. First, some studies were conducted a few years ago in Washington, the results of which were published by the

Smithsonian Institution, the object of which, among other things, was to find out to what the drowsy feeling that we have all noticed when in ill-ventilated places was due. These studies did not reach any definite conclusion as we read them, but seem to point to the conclusion that 3,000 cu. ft. of air per person per hour was a large figure. The authors of the paper were, however, very cautious, and while their studies did not succeed in isolating any poisons given off from the bodies of human beings that would produce drowsiness, and possibly more serious consequences, they finally say in so many words that their experiments do not entitle them to change the ordinarily accepted figure.

Other points bearing on this question are the experiments made with the human calorimeter, in connection with Wesleyan University, at Middletown, Conn., by Professor Atwater. In conversation with him on the experiments made with this calorimeter, it was stated that there seemed to be no complaint from the inmates due to an increase in the amount of carbonic acid. The analyses of the air taken out of the calorimeter might indicate very much larger amounts of carbonic acid than any figures given above show, and yet the inmates did not complain of drowsiness or of any unpleasant feeling. If, however, the amount of moisture in the air got much above the normal, drowsiness or unpleasant feelings, with occasional headache, seemed to result. With the present state of our knowledge, the best that can be said perhaps is that the question as to the absolute amount of air required for good ventilation is in a moderately uncertain condition, and that there is need for much more definite work on the subject than has yet been done. For information it may be stated that so high a figure as 180,000 cu. ft. of air per car per hour has not been attempted in the experiments referred to above on the Pennsylvania Railroad. To get such an amount of air as this through a car per hour, and to warm it in severe weather, is a more difficult problem than we have ever attempted to solve. The experiments on the Pennsylvania Railroad have been confined to an attempt to get 60,000 cu. ft. of air per car per hour, or 1,000 cu. ft. of fresh air per person per hour through the car.

Before proceeding to describe the system of ventilation finally adopted, two points farther may perhaps be reasonably touched upon. The first of these has a bearing on the attempts made so often by those who have apparently not sufficiently studied the

problem, to get ventilation by putting on ventilators. In one of our experiments as many as 20 Globe ventilators were put in the roof of a car, proper appliances having been made use of, as was supposed, to admit sufficient air to the car. It was found as the result of these experiments that the ventilators on the front end of the car, especially when the wind was ahead, acted so vigorously in producing a vacuum in the car that actually the Globe ventilators on the rear portion of the car took in air instead of exhausting it, as it would naturally be supposed they would do. In other words, this experiment, we think, most conclusively proves that there must be a proper relation between the supply of air and the exhaustion of air. It may be worth mentioning that the peculiarity found when the car was running was that the rear of the car was a great deal colder than the front end, and in the attempt to find why this was so, the point mentioned above, of the cold air coming in through the Globe ventilators in the rear of the car was developed. We are very firmly convinced that exhaustion of air from any space is not ventilation. There must be fresh air supplied as well as the removal of all polluted air from the space that it is sought to ventilate.

One question further: How is it possible to measure the amount of air that goes into and out of a car per hour? We have already spoken about the enormous amount of air required, according to present ideas, for successful ventilation, and also that the attempt had been made in the experiments on the Pennsylvania Railroad to get 60,000 cu. ft. of fresh air through the car, but how do we know, or what means is there for telling whether we get 60,000 or 40,000 or 100,000 cu. ft. of air per car per hour through the car? This problem is not so simple as it looks. Obviously, with the leakages and the friction of the air in the ventilators, any attempt to measure the amount of air by taking the velocity of the current issuing from the Globe ventilators would be fallacious. The air issues not only from the Globe ventilators which are put on for the purpose, but also from the ventilators over the lamps. Furthermore, any attempt to measure the velocity of the current from the intakes would probably result in failure, owing to the fact that around doors and windows there are constant leakages; so it is obvious that some means of measuring the air other than by taking the size of the apertures and velocities through these apertures must be made use of.

The data already mentioned give us a means of getting at what we are seeking. It has already been stated that the average of a mixed community gives off 6-10 of a cubic foot of carbonic acid per person per hour. If now we have a definite number of people in the car, and can safely assume that on the average a certain amount of carbonic acid is given off per person per hour, it is obvious that we can very readily ascertain how much carbonic acid per hour we have to deal with; and this being known, a very simple calculation, as already shown above, will give the amount of air required to dilute this to any given figure. If, for example, it is found that the amount of carbonic acid in a sample of air from a car shows 11 parts in 10,000, we have the data to calculate how much air passes through the car per hour, as follows: It has already been stated that the air normally contains four parts of carbonic acid in 10,000. If we diminish the 11 by this 4, it is obvious we have 7 parts of carbonic acid per 10,000 of air given off from the passengers. There being, say, 60 people in the car, each giving off an average of 0.60 of a cu. ft. of carbonic acid per hour, it is obvious that we have 36 cu. ft. ($60 \times 0.60 = 36$) of carbonic acid to deal with, and our problem really is, How many cubic feet of air are required in order to dilute 36 cu. ft., so that the amount will be 7 parts in 10,000 of the air? By a very simple proportion, if 10,000 cu. ft. of air contain 7 parts of carbonic acid given off by the passengers, how many thousand cubic feet of air will be required to dilute 36 cu. ft. to the same ratio? Making the calculation, we get, under the conditions supposed, a trifle over 51,400 cu. ft. It will be understood that in this calculation extreme accuracy to the amount of a few cubic feet is not aimed at, and also that since the capacity of a car is so small, and the air in the car changed so frequently, the amount of air in the car to start with has been ignored.

Let us now proceed to an examination of the ventilating system finally adopted as the result of all the experiments. Accompanying photo-engravings show the essential details; Fig. 1 gives a general view of the system. The left hand portion of the figure shows a vertical section through the hood "A," down-take "B," air passage "C," floor apertures "D," and heater box "E." The right hand portion of the figure shows a vertical section through the longitudinal center line of the car, bringing to view the exits from

the heater boxes "F," one under each seat. The arrows indicate the direction of the air currents. The appendage "G" allows the air passage "C" to be cleaned; it being found that small, very light cinders collect in this passage. It was at first thought that if a small hole was left in this appendage the air currents in the air passage would carry the small cinders out; but experience shows that this is not the case, and it has been found essential to occasionally remove portions of the false bottom in order to clean the air passage.

As will be observed from an inspection of Fig. 1, the system in its outline is very simple. It consists in taking air from the outside in through two hoods at diagonally opposite corners of the car, thence through the down-takes underneath the hoods to the spaces, one on each side underneath the car floor, bounded by the floor, the false bottom, the outside sill, and nearest intermediate sill. These spaces, which are in section about 14 by 7½ ins., extend the whole length of the car. From these spaces the air passes up through the floor by means of proper apertures, over the heating systems and thence out into the car, and finally escapes from the car through ventilators situated on the center line of the upper deck.

The hood and down-take construction is shown in Fig. 2. It will be noted that a wire gauze "H" covers the two faces of each hood, the object being to exclude cinders of any appreciable size, especially such as might lead to incipient fires. The flap valve "I" is so manipulated that the air has a free passage into the down-take "B" from the direction in which the car is moving. This valve is controlled by a mechanism operated by the trainmen inside the car, the pointer on the operating device "J" indicating the direction in which the valve should be open. The door "K" in the down-take permits the operating devices for the flap valves to be connected, and also allows a chance for inspection.

It is interesting to note the strong downward current of air when these doors are opened for a moment, while a car is in motion. The down-takes have each an area of about 100 sq. ins. In the down-take just below the mechanism operating the flap valve is a butterfly valve "L," by means of which it is possible to very nearly close the down-take. The normal position of this valve is open, the trainmen being instructed to close it only (1), when going through tunnels, in order to exclude foul air, or (2), when stand-

ing in stations with the locomotive detached, it is desired to keep heat in the car as long as possible. In most passenger cars the sills are connected together at short intervals by cross bracing. In order to form the air passage or conduit between the outside sill and the nearest intermediate as above described, it is necessary to remove this cross bracing. In place of it, in order not to weaken the car structure, braces of iron are used in the form of open frames. These allow a free passage for the air, and, being bolted to the sills, they are believed to strengthen the car rather than weaken it.

Fig. 3 shows the cross section of a car. The right hand half of the figure is a section through the middle of a seat showing the air passage "C," the brace "M," the heater box "E," the heating pipes "N," and a vertical section of the tube "F," which carries the heated air from the heater boxes to the aisle of the car. The left hand half of the figure is a section mid-way between two seats showing the air passage "C," the brace "M," the floor aperture "D," the heater box "E," the heating pipes "N," and an outside view of the tube "F." The apertures in the floor are made by cutting slots 2x12 inches through the floor itself. There is one of these slots between each two seats on both sides of the car. In the early stages of the experimental work, it was thought that it might be desirable to make the slot through the car floor continuous, but a little experience showed that this was unnecessary; moreover, the floor system is a part of the strength of the car, and after pretty careful consultation over the matter it was decided that it would hardly be wise to weaken the car to this extent. The heating system consists, as is seen, of pipe radiators. The pipes extend nearly the whole length of the car and are enclosed in a continuous boxing $5\frac{1}{2}$x$8\frac{1}{2}$ inches, inside dimensions. The heating substance is steam from the locomotive, although with proper changes as to amount of heating surface hot water may be used. The steam is supplied to the radiators at the middle of the car, and the condensed water is returned to the middle of the car also, and from there allowed to flow through proper traps to the track. The distance between the centers of the galvanized iron tubes, F, carrying the heated air from the heater boxes to the aisle, under two contiguous seats, is $35\frac{1}{2}$ inches and mid-way of this distance the 12 inch slot through the floor is situated. It will thus be seen that the cold air coming up through the floor into the heater boxes divides

and passes in contact with the heater pipes each way to the tubes under the seats which carry it to the aisle. This amount of contact with the proper amount of heating surface in the car, and with sufficient steam pressure, is found to be abundant to properly warm the car, even in severe weather. It is perhaps unnecessary to add that from the tubes under the seats the air disseminates through the car and finally passes out through the ventilators in the roof. The tubes under the seats serve in some measure as a foot warmer.

During the experimental work attempts were made to take the heated air out from the heater boxing, through registers in the sides of the boxing, into the space between each two seats. But this was found to be so objectionable to the passenger sitting next to the window that it was abandoned. Also an attempt was made to take the heated air out through apertures in the top of the boxing between each two seats, the idea being to have a current of warm air direct from the radiators pass up along the windows, to neutralize their chilling effect. But it was found that this aperture served as a convenient receptacle for materials thrown in by the passengers. Still further, during the experimental work, the slots in the car floor were made 4 ins. long and spaced 4 ins. apart, and the radiators were fitted with tin shields so arranged as to keep the air in contact with the radiators as long as possible, but none of these devices worked as well as the arrangement finally adopted.

The control of the ventilating system, that is, the devices by which the amount of air taken into the car is increased or diminished, is in the ventilators situated along the center line of the upper deck. The ventilators thus far used are of the type known as the Globe Ventilator. There are seven of these of the six inch size, five for use over the lamps, and one at each end of the car. The end ventilators differ somewhat in construction from those used over the lamps. Fig. 4 shows the end ventilator. It will be noted that it consists practically of a register valve and the necessary appliances by means of which this is connected with the ventilator itself, and attached to the car roof. The apertures in the register, when the valves are open, are a little more than equal to the area of the six inch ventilator tube. When the valves of these end ventilators are closed, no air passes through except small leakages. The appliances for

operating the valves are so arranged that when the valve handle stands lengthwise of the car, the valves are wide open; when crosswise, the valves are closed. It is possible for the valve handle to have any desired intermediate position, with corresponding control over the amount of air passing through the ventilator. The ventilators over the lamps are shown in Fig. 5. It will be observed that they have the same essential parts, viz: a register valve and arrangements for fastening to the car roof, and connecting with the Globe Ventilator. They have in addition a smoke bell as an essential part of the register, which smoke bell is prolonged upward, by a tube three inches in diameter. This smoke bell and tube are never closed. The valve system surrounds the smoke bell, and is operated in the same way as that of the end ventilators. It will be observed that the smoke bell and its tube provide a constant opening of about one-fourth of the area of the ventilators over the lamps. As will appear later, however, the diminution in the amount of air passing through the car, when all ventilators are closed, does not correspond to these figures, probably due to leakages in the valves, and to greater velocity of air through the smoke bell, when the valves are closed.

During the experimental work, and, indeed, on some of the first cars fitted up, the ventilators were all of the end type, and were located between the lamps. But it was found early in the experimental work that the lamp ventilators were so important an element in the problem that they could not be ignored. With six ventilators of the end type, and five lamp ventilators, more air was taken through the car than could be warmed in severe weather, and accordingly on the first cars fitted up, the lamp ventilators were partially closed, only a two inch diameter aperture being left for the escape of the lamp gases. But this resulted in smoking the head lining, and accordingly the combined ventilator was devised for use over the lamps. The permanent three inch aperture in the combined ventilator manages the lamp gases very successfully. It will not escape notice that all the ventilators may be closed, or all may be left open, or a part closed and a part left open, thus giving great flexibility to the system.

It will also not escape notice that thus far no reference has been made to the movable deck sash which is in so many cars, an important element in the ventilation of the car. Upon this point it may be said that in the system of ventilation which

we are describing the movable deck sash has no place. The deck sash are purposely made tight and immovable, with no detriment to the ventilation, and with very gratifying improvement in the behavior of the car lamps. Lamps which formerly gave much difficulty due to cross drafts between open deck sash can be used with very satisfactory results in cars fitted with the new ventilating system. A further marked advantage of fixed deck sash is the entire absence of cold air currents falling on the heads of the passengers, which is so unpleasant a feature of the movable deck sash. This point alone is no small item in favor of the new system, and when it is remembered that no cinders can come in through the fixed deck sash, it seems evident that the concomitant advantages of the methods adopted in this system are not inconsiderable.

The experimental work having led up to the construction above described, it remained to test the system and see what results it would give. The first tests were made to demonstrate whether the air currents would flow in the direction desired when the car is standing still. It is well known that some ventilating systems depend for the proper movement of the ventilating air currents on the movement of the car itself, and that when the car is standing still the ventilating air currents move in the wrong direction. In the system above described this difficulty, however, does not occur. It is, of course, fair to be said that when there is no heat in the car, and when the lamps are not lighted, there is very little movement of the ventilating air currents in either direction when the car is standing still; but definite experiments clearly show that when there is heat in the car or when the lamps are lighted the ventilating air currents move in the direction desired. This is easily seen by holding smoking waste at the ventilators, and also, as above mentioned, by observing the motion of the air in the downtakes through the opened door. It is not difficult to see why this should be so, since the exits from the Globe ventilators are nearly 2 ft. higher than the top of the hood at which the air enters. It may not be amiss to mention that when a car has been closed and standing on a siding for some time during very cold weather and is then put in a train and given heat, there is a little difficulty in getting the air currents started in the right direction. This is due to the fact that the column of cold air between the car floor and the tops of the ventilators is longer than the column of cold air from the bottom of the air conduit between the sills to the top of the

hood. The difficulty is readily overcome by opening the car doors for a few minutes and allowing the cold air to pass out.

Another point which caused some anxiety during the development of the system was soon put to test. It is well known that the construction of the Globe ventilator is such that when moving through the air on top of a car or when the wind blows past the ventilator, a suction is produced in the ventilator tube. This behavior of the Globe ventilator is one of the items relied on to cause the proper amount of ventilating air to pass through the car when in service. Moreover, the hood, when the car is in motion, acts as an injector and forces air into the car. Now it is obvious that if the exhausting action of the ventilators is in excess there will be a slight vacuum in the car; on the other hand, if the injecting action of the hood is in excess, there will be a slight plenum in the car. In the experimental work every effort was made to secure a plenum in the car. But limitations of space inside the car, and clearances outside, rendered the efforts in this direction not quite as successful as could be desired.

It should be mentioned that experiments demonstrating whether a plenum or a vacuum exists in a car at any moment, are difficult to make, and are more or less unsatisfactory at best, and although some time has been spent over this point and a number of experiments made, the question of a plenum or a vacuum is not yet fully settled. The best that can be said is that there is no strong evidence that when the system is in normal operation there is a plenum. The tests indicate very closely a balance with a slight preponderance toward a vacuum. Such being the case, it would naturally be expected that cold air currents would flow in through every available crack or crevice, and especially that contaminated air would be drawn from the closet into the body of the car. In actual practice it is found that the difficulties from cold air currents through cracks and crevices are so small as to be ignorable. The possibility of contaminated air from the closets gave more anxiety, and as a precautionary measure a 4-in. Globe ventilator was put in the roof of each closet. With this construction and with the close balance between plenum and vacuum in the car as above stated, no difficulty whatever has been experienced due to contaminated air from the closets. Indeed, many and oft-repeated tests show that when the car is in motion the actual air movement is toward the closet rather than from it.

The above preliminary tests having been made, it became interesting and essential to know positively what the system would do in the way of furnishing fresh air to the cars. In order to decide this question, a car fitted as above described was loaded with men from the shops, who were paid for their time, and were under the charge of a foreman so that they could be controlled in the matter of opening doors and windows. With this car a trip was made early in December, from Altoona to Johnstown and return, a distance of about 40 miles each way. Rubber bags and hand bellows were employed to secure samples of the air in the car. Steam heat was necessary since the temperature outside was from 23 to 30 degrees Fahr., and neither door nor window was opened during the trip, except that after the proper samples of air had been taken at Johnstown the men were allowed some freedom, since a wait of a couple of hours must ensue before the return trip could be made. The air samples for analysis were taken by pumping air into the rubber bags by means of a hand bellows, moving from one end of the car and back again in the aisle during the operation, and taking the air from about the level of the heads of the passengers. The analyses were made immediately after the return and always the same day. During this test there were 52 people in all in the car, including those who took the samples, and since they were full grown working men the amount of carbonic acid given off per person was assumed to be 0.72 of a cubic foot per hour. This is the amount stated by the authorities as characteristic of working men.

It is fair to say that during the development of the system this same trip was repeated a number of times, as successive modifications were tried, and during the studies on this subject probably not less than thirty to forty tests of the air from cars have been made in the laboratory of the Pennsylvania Railroad Company. The final tests only are given below. In making the air analyses carbonic acid only was determined, and from this was calculated the amount of fresh air taken through the car per hour by the ventilating system, the method used being the one described earlier in this article. The figures obtained on the trip mentioned are as follows:

WESTBOUND.

	Per cent. of Carbonic Acid.	Cubic Feet of Air Per Car Per Hour.
All Globe Ventilators closed, Bennington	0.18	26,700
All Globe Ventilators open, Buttermilk Fails,	0.10	62,400
All Globe Ventilators open, standing 20 minutes at Johnstown	0.21	22,000

EASTBOUND.

	Per cent. of Carbonic Acid.	Cubic Feet of Air Per Car Per Hour.
All Globe Ventilators closed, Cresson	0.14	37,400
All Globe Ventilators open, McGarvey,	0.10	62,400
All Globe Ventilators open, standing 29 minutes at Altoona	0.20	23,400

In explanation of the figures it may be stated that the stations mentioned denote locations at which air samples were taken. Bennington, on the schedule used, is about 23 minutes from Altoona; Buttermilk Falls is about 57 minutes from Bennington, and Johnstown is about 10 minutes from Buttermilk Falls. Returning, Cresson is about 42 minutes from Johnstown, McGarvey about 20 minutes from Cresson, and Altoona about 5 minutes from McGarvey. These figures will give some idea of the interval between samples.

As has already been stated, the system was designed to supply 60,000 cu. ft. of fresh air per hour to a car, and it will be noted that when all the Globe ventilators were open, that is when the system was working normally as designed, the actual amount of fresh air obtained, was a trifle above the desired figure, as is shown by the samples taken at Buttermilk Falls and McGarvey. It should be stated that the actual amount of air supplied from time to time is affected by several conditions. The speed of the train has an influence, also the differences in temperature inside and outside of the car, and the direction and force of the wind. Just how much each of these variables amounts to is not known. It would require a number of tests under each of the varying conditions to decide these points definitely, but as the west-bound schedule was a slow one and the east-bound a more rapid one, it seems fair to assume that the system fulfils the requirements for which it was designed fairly well. It is also interesting to note that when the Globe ventilators were closed; that is, when the designed control was applied, the amount of air supplied was cut down approximately one-half, as is shown by the samples taken at Bennington and Cresson. In other words, the control makes it possible to reduce the amount of fresh air when it is desired to do so, as for example when there are few passengers in a car, or perchance

in extreme cold weather, when the heating system may not be quite sufficient to warm the full amount. Finally, the samples taken at Johnstown and Altoona show what the system does, when a car is standing on the track, as at stations en route. It would, of course, not be expected that the same efficiency would be shown when the car is at rest as when it is in motion, and indeed this hardly seems essential. It will not escape notice that the difference between the amount of air supplied standing still and when the train is in motion, measures the effect of the movement of the train on the system. The tests above given were considered to indicate that the system was fairly satisfactory, as far as amount of fresh air is concerned. Two points further remain to be considered. These are the warming of the car and the exclusion of objectionable matter, such as smoke and cinders

The heating arrangements for which the ventilating system was designed had one square foot of heating surface for about 240 cubic feet of ventilating air per hour when the system was in full normal operation. Under these conditions it is obvious that the temperature in the car would be a function of the steam pressure maintained in the radiators and of the temperature of the outside air. Clearly it would be expected that if the amount of air supplied is constant at any given condition of the thermometer outside, the temperature inside would vary with the steam pressure; or again, if the steam pressure is constant, and the amount of air also constant, the temperature in the car would depend on the outside temperature. In order to find out exactly what the system would do in the matter of car heating a car fitted as above described was run from Altoona to Harrisburg a distance of about 132 miles, in January, when the temperature outside during the whole trip was from 10 to 13 degrees Fahr. above zero. The car was without passengers, in order to afford opportunity for manipulation. The steam pressure maintained, although not measured on this particular car, was, from readings on the gauge on the locomotive, believed to be about 20 lbs. During the trip the following points were very satisfactorily demonstrated: 1st, There is no difficulty whatever in keeping the car comfortably warmed in such weather with the ventilating system in full normal operation. The thermometer on the bell-cord hanger in the middle of the car, at no time

throughout the whole trip showed less than 70 degrees Fahr. and most of the time was from 73 to 75, and on one occasion reached 77 degrees. 2d. The distribution of heat throughout the car was entirely satisfactory. Thermometers in different parts of the car did not show differences of more than two or three degrees. 3d. Diminishing the amount of air supplied to the car, increased the temperature, which is what would be expected. Upon this latter point some further experimentation is desirable. The amount of work planned for this trip was full enough for the time, and the experiments on increased and diminished supply were not started until toward the end of the trip. The indications, however, were clearly as above stated.

An interesting feature developed during this run was in regard to the behavior of the two sides of the car. It will be remembered that there are hoods and down-takes on diagonally opposite corners of the car, one being, therefore, on the front end and the other on the rear end of the car when it is in motion; also that each down-take connects with its own radiating system, and that these are entirely independent, except that they take steam from the same point of supply. Are now both sides of the car equally efficient in supplying air when the train is in motion? The indications obtained during the trip above mentioned are that this depends largely on the direction of the wind. With the wind dead ahead, both sides seemed to be equally efficient; with the wind ahead and from the right of the line of the train movement, the right-hand side of the car seemed to be most efficient, and with the wind from the left, the left-hand side of the car seemed to do most of the ventilating. The direction of the wind was noted by observing the locomotive smoke and the movement of the air by holding delicate anemometers at the air exits in the car under the seats.

Tests subsequent to those mentioned above, seem to put beyond question the possibility of keeping the car abundantly warm during any weather, even when the ventilating system is in full normal action. Careful observations of temperature were made by a competent person during a trip from Philadelphia to Altoona, a distanct of about 237 miles, with the thermometers outside from 2 to 5 degrees Fahr. below zero most of the distance. It was easy to keep the thermometer on the bell-cord hanger 70 degrees and above. No record was made of steam pressure

on the car, but 30 lbs. were used on the locomotive. An interesting feature developed during this trip, viz., the windows were heavily frosted at starting, owing to a little leak in the steam pipes while the car was being warmed up in the station. This frosting entirely disappeared in the course of an hour and a half, owing to the constant passage through the car of dry warm air.

Finally, in regard to possibilities of keeping the car warm, observations were made on a day train during the blizzard of February, 1899. This train was blocked by snow on the east end of Rockville bridge, near Harrisburg, for over four hours. The location gave full sweep for the wind blowing down the Susquehanna River, and at times the cars would sway from the force of the blast. One of the five trial cars happened to be in this train, and during the time mentioned frequent observations were made on the temperature. At no time was any discomfort experienced, and at no time did the thermometer on the bell-cord hanger show less than 70 degrees Fahr.

In regard to the amount of steam required to warm the ventilated cars, no very positive data have been obtained. The number of cars fitted with the new system is not yet large enough to make the question a very serious one. It seems evident that more steam will be required than if the cars were not ventilated, but thus far no serious difficulties have been experienced. A few through trains having from three to five ventilated cars in them have been operated with perfect success for over a year.

A single point bearing on the use of steam may be worth mentioning. At one time during the experimental work, a gauge fitted to show both pressure and vacuum was put on the radiator. At that time the system of heating in use was the return system, the water of condensation being taken back to the locomotive by means of a pump, which often produces a vacuum in the return pipe, which vacuum may extend into the radiator itself. On the occasion described the car was in a train moving about 40 miles an hour, the temperature outside about 20 degrees Fahr., and a very large volume of air, probably over 100,000 cu. ft. per hour, was passing through the car. The gauge on the radiator was indicating a vacuum of 5 or 6 pounds, when suddenly the train was stopped by signals. In a very short time, probably less than two minutes, the same gauge showed a pressure of 10 lbs. The explanation seems to be that while the train was moving, the heat was taken

away from the radiators so rapidly by the incoming cold air that the steam condensed as fast as it was supplied, and the vacuum of the return pipe prevailed in the radiator; while, when the car stopped, the flow of air and consequently the removal of heat was so diminished that the steam supply was able to produce a pressure in the radiator. The vacuum appeared again, a short time after the train started

In regard to the exclusion of smoke, cinders, dust, noxious gases, etc., it is to be confessed that if any of these substances are suspended in or mixed with the air which comes to the hoods, they cannot fail to be taken in along with the air. Cinders, however, of any appreciable size, are excluded by the gauze over the hoods. Small cinders that pass the gauze apparently are deposited in the conduit between the sills. The location of the hoods on the top of the lower deck is believed to very greatly diminish the possibility of dust from the track being a serious source of annoyance. The smoke from the locomotive with the noxious gases which it carries is usually considerably higher than the hoods, or is diverted on one side of the train or the other by the wind. This leaves only the conditions concomitant to long smoky tunnels to be especially provided for. The closure of the valves in the downtakes and the rapid change of air in the car by the system, only about four minutes being required to completely replace the air in a car, after it has passed the tunnel, so greatly mitigate this difficulty that no serious trouble has thus far been experienced from the introduction by the ventilating system of objectionable matter from without.

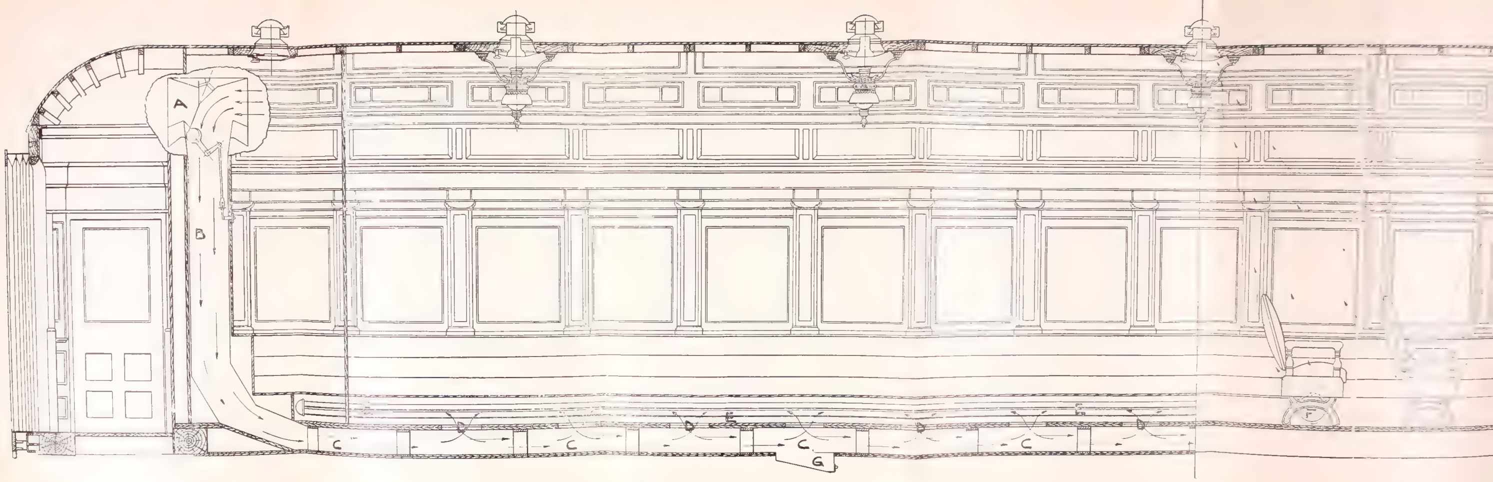
It may be fairly stated that practical experience with the system on the road has thus far been very gratifying. Both passengers, officers and trainmen seem to find in the new system such an amelioration of previous conditions that it is not rare for them to pronounce it a marked success. The tendency to open the windows is very greatly diminished, and the possibility of running with closed doors in the heat of summer is clearly noticeable.

The above was written in May, 1901, and, except for some few changes to describe present practice, is given as originally written. At the present time (July, 1904), the Ventilating System, as

described, is in daily use on 800 cars on the Pennsylvania Lines East of Pittsburg and Erie. It is being applied to all new cars as they are being built, and to the older cars in the equipment as fast as conditions will warrant. It has also been applied to 200 cars on the Pennsylvania Lines West of Pittsburg, and to some cars on the Baltimore and Ohio Railroad and on other railroads. It has not yet been applied to a Sleeping Car.

It is fair to add that although the experimental work in developing the system was principally done by and under the charge of the Laboratory force of the Pennsylvania Railroad Company, the suggestions and assistance of a number of others of the expert staff of the General Superintendent of Motive Power, under whose general supervision all tests and experiments are made, has been of the utmost value.

The very earliest experimental work was done by Mr. J. F. Elder, Chief Car Inspector; Mr. Chas. Lindstrom, Assistant to the Mechanical Engineer, and Mr. W. W. Todd, General Car Inspector for the Lines West of Pittsburg. The air analyses were made by Mr. F. N. Pease, Principal Assistant in the Pennsylvania Railroad Laboratory. Particularly valuable has been the assistance of Mr. A. S. Vogt, Mechanical Engineer, without whose hearty co-operation the results obtained would hardly have been possible.



A
B
C
D
E
F
G

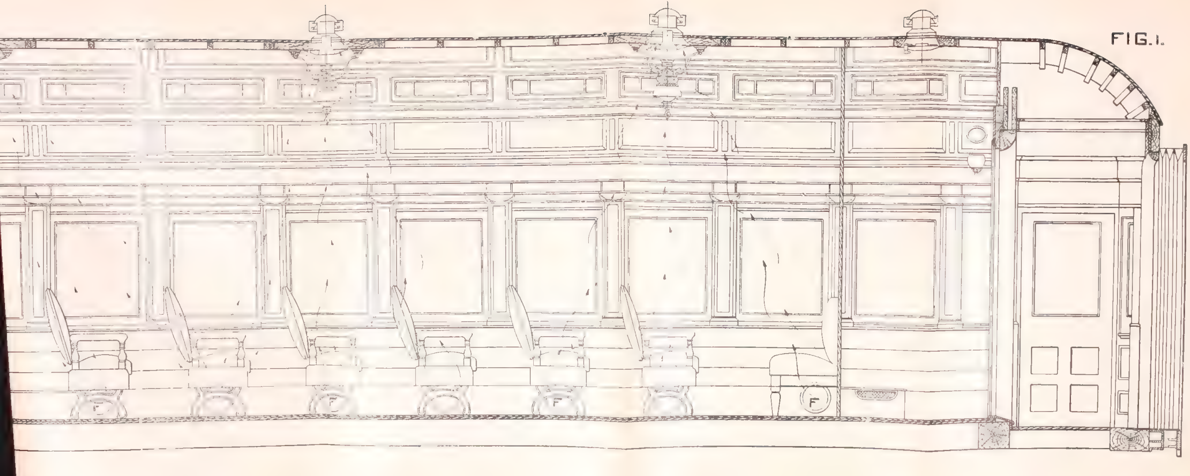


FIG. 1.

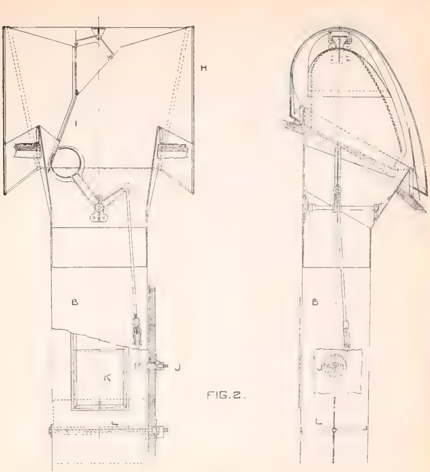


FIG. 2.

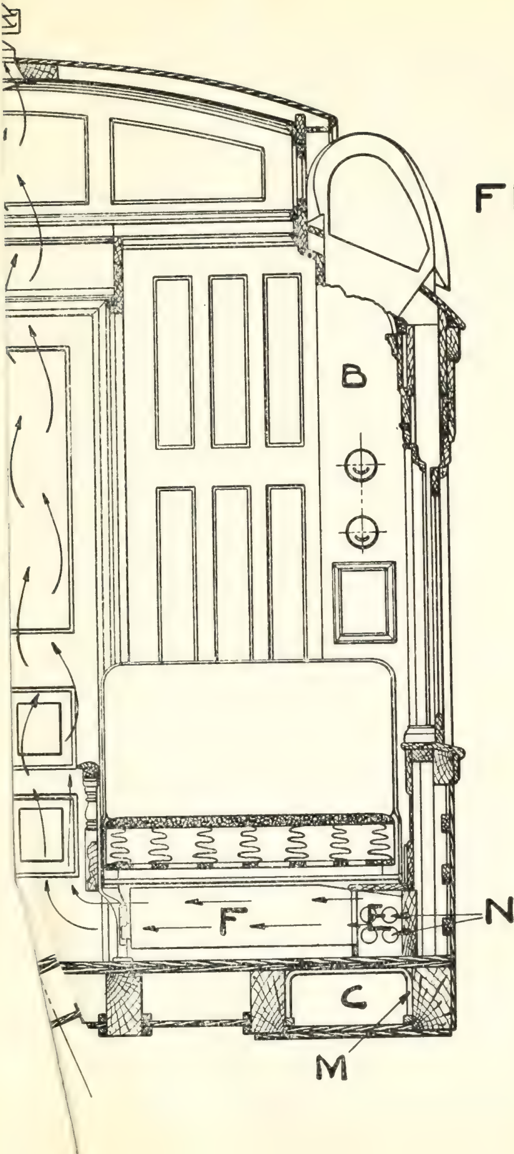


FIG. 3.

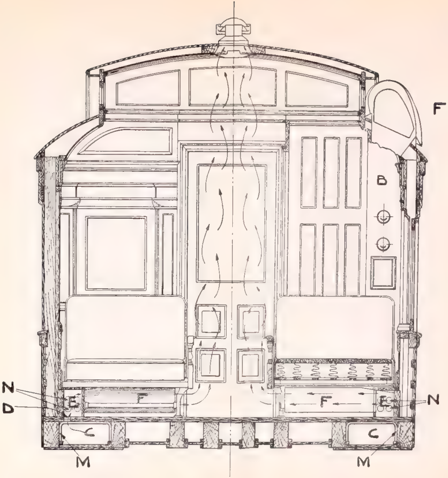


FIG. 3.

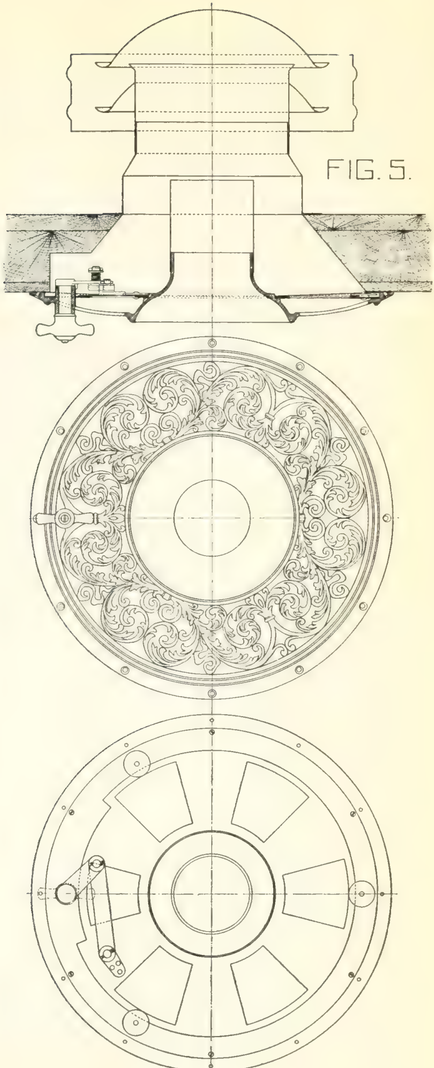


FIG. 5.

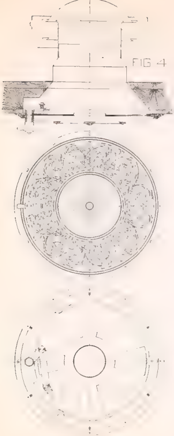


FIG 4

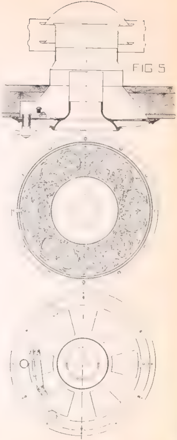


FIG 5